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**Lightning Detection Efficiency Analysis Process:
Modeling Based on Empirical Data**

Prepared By:	John T. Rompala
Academic Rank:	Professor
Institution and Department:	University of Wisconsin-Stout Physics Department
NASA/MSFC Directorate:	SD-60
MSFC Colleague:	Dr. Richard Blakeslee

Introduction

A ground based lightning detection system employs a grid of sensors, which record and evaluate the electromagnetic signal produced by a lightning strike. Several detectors gather information on that signal's strength, time of arrival, and behavior over time. By coordinating the information from several detectors, an event 'solution' can be generated. That solution includes the signal's point of origin, strength and polarity.

Determination of the location of the lightning strike uses algorithms based on long used techniques of triangulation. Determination of the event's original signal strength relies on the behavior of the generated magnetic field over distance and time. In general the signal from the event undergoes geometric dispersion and environmental attenuation as it progresses. Our knowledge of that radial behavior together with the strength of the signal received by detecting sites permits an extrapolation and evaluation of the original strength of the lightning strike. It also limits the detection efficiency (DE) of the network. For expansive grids and with a sparse density of detectors, the DE varies widely over the area served. This limits the utility of the network in gathering information on regional lightning strike density and applying it to meteorological studies.

A network of this type is a grid of four detectors in the Rondonian region of Brazil. The service area extends over a million square kilometers. Much of that area is covered by rain forests. Thus knowledge of lightning strike characteristics over the expanse is of particular value.

I have been developing a process that determines the DE over the region [3]. In turn, this provides a way to produce lightning strike density maps, corrected for DE, over the entire region of interest. This report offers a survey of that development to date and a record of present activity.

Peak Current Distribution

In an ideal network with a 100% DE, complete information on all lightning strikes is gathered using reliable algorithms. One feature that would be included is the peak strength (I_0) of events. Those peak currents cover a wide spectrum of values ranging from below a single (+/-) kiloAmps to a few hundred (+/-) kiloAmps. An example of such a distribution is given in Figure 1. The vertical axis represents the fractional event density, that is, the fraction of all observed events that had a peak current with the range $I_0 \pm \Delta I$. The area under the curve is one.

The data set depicted shows Rondonian data for November 23, 2002. It represents a nearly 100% DE since it was restricted to a record of strikes occurring in relatively small region central to the four sites. The shape of the distribution follows the general shape of the gamma probability distribution [4]. The DE Analysis Process under development assumes that this profile is characteristic of the events occurring over the entire region. Though the area density of lightning strikes may vary over the region, it is assumed that this distribution spectrum remains constant.

It examines the operational features of network detectors, and the incoming signal's electromagnetic character to determine the greatest minimum peak current generated at a location needed to produce detections from various combinations of detectors. With these cutoffs determined, it is possible to estimate what fraction of the full peak current spectrum goes undetected at that local. This establishes that location's DE level (which can be a composite result or determined as a function of various detector combinations).

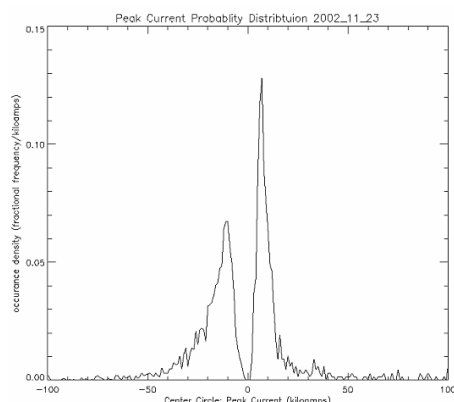


Figure 1: Peak Current Distribution

Radial Considerations:

This greatest minimum detectable peak current comes about, in part, due to range effects. This cutoff is fixed by the range characteristics of the electromagnetic signal and sensitivity of the detector. It is widely accepted that the general dispersion of the signal follows the pattern of a pulsed current in a long straight wire. The resulting functional relation between signal strength and range is inverse ($1/r$). To accommodate variations from this ideal construct, the comparable relation for a lightning event introduces a power value, P , $(1/r)^P$.

Signal attenuation due to effects arising from the electrical character of the terrain traversed, is taken to be exponential ($e^{-a/r}$). The attenuation parameter, a , represents the distance a signal must travel before signal drops to $(1/e)$ of its original value. Operational values vary from a few thousand kilometers to a few hundred thousand kilometers.

These radial characteristics of the electromagnetic signal come into play in two aspects of the development of this DE Analysis Process. The first is the most direct, the determination of the greatest minimum peak current. It is critical that the behavior signal's range behavior be understood before a reliable estimate of the greatest minimum strike strength can be established.

The peak current distribution used, as a model for the entire region is itself produced using algorithms using these interpretations. The subregion used for gathering data for a nearly perfect DE distribution is near all sites thus range issues are not as evident here as they are in remote areas of the service region. Nevertheless, consistency requires that the same values of power and attenuation be used in both steps of the analysis. This becomes an absolute requirement if that analysis is to include an evaluation of those parameters.

Toward that end, the present effort first involved rewriting the algorithms for the DE Analysis Process in a polar format [4]. The central and other subregions now have circular shapes (i.e., circle for central region, rings for outer regions).

Reference to Fundamental Data Sets

In the initial stages of development of the DE Analysis Process, a single data set was employed. That data set already presented processed peak currents and did not reference the sites used in determining solutions. Results were always compared to all solutions since details of those solutions were not part of the data set. Again for consistency, it is important to refer back to raw input signal to the detectors. In this way assurance can be given that the data was processed using the same parameters and techniques used in the application of the DE Analysis Process.

To achieve this level of assurance, code was written which refers back to data sets containing the strength of the magnetic field signal received by the sensors and the sites involved in solutions. This was also done to provide a platform for an eventual accommodation and evaluation of the probable data processing technique upgrades.

LLP to Peak Current

The transform from of the magnetic field strength of the incoming signal to the peak current generated in the lightning event is based on a series of triggered lightning experiments carried out by Orville [2]. These experiments involve sending a sounding rocket into an atmospheric electrical environment suitable for producing lightning. A conducting wire trails the rocket into electrically charged clouds. This wire provides a ready path for a lightning strike to follow to ground, while the rocket/wire combination ‘triggered’ lightning events under suitable electric field conditions. The lightning strike so triggered vaporizes the wire but in the process leads to a ground location where instrumentation records the peak current of the strike. These peak current values were correlated to signals received by detectors at known distances from the lightning strike. The readings, historically expressed in ‘LLP units,’ were normalized, giving the readings of a detector at a ‘normalized’ distance. These experiments indicated a linear relation between normalized LLP signals and the peak current prompting that signal. That data is reviewed periodically with the data spread permitting several interpretations [1]. The data set included strike with a limited peak current. The extrapolation of these triggered lightning results to higher current events and to distant, naturally occurring lightning strikes requires care. The code written for the DE Analysis Process includes interactive features fostering the eventual implementation modifications in these areas.

Validation

Two sample applications of the revised process were carried out. The first dealt with changes in the attenuation factor from 10^3 km to 10^5 km. Corresponding projected changes in DE for Rondonian network were formulated. The second case monitored the variations in the peak current distribution introduced by various forms of the LLP to peak current relation.

As designed, the DE Analysis Process and assumptions can be evaluated by using it to replicate the empirical data peak current distributions derived from the observed data. Figure 2, compares

empirical data (green) for a subregion about the center of the grid to modeled distribution (black) for the same region under comparable detection conditions

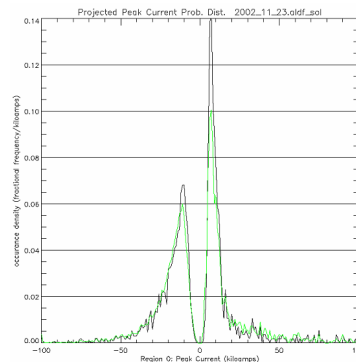


Figure 2: Empirical and Modeled Distributions

Conclusion

Confidence in the validity of the process and in its potential for application grows. It was originally meant to serve as a strictly operational tool for gaining the detection efficiency of the network under various conditions. It has already served a role in the clarification of operational parameters. It has shown potential for an expanded role in this regard. If the validity of the process can be fully established, it can be applied to meteorological studies. Being developed in conjunction with this empirical based modeling of the peak current is an analytical model. That formalism will eventually lend itself to an analysis of peak current distribution physics.

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